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Novel Low Viscosity Zinc Oxide, Iron Oxides and Erioglaucine Sunscreen Potential to Protect from Ultraviolet, Visible Light and Near-Infrared Radiation

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Abstract

Despite the widespread recommendation and use of sunscreens and ultraviolet blocking materials, solar-induced skin damage and photoageing continues to pose a problem to human health worldwide. We have previously reported that solar visible light and near-infrared also contribute to skin damage and photo ageing. Most commonly recommended sunscreens are only effective throughout the UV spectrum, offering no protection from visible light and near-infrared. A possible solution could be to augment sunscreens with metal oxides which block visible light and near-infrared radiation. To evaluate the enhanced solar-spectrum blocking ability of novel low viscosity sunscreen containing zinc and iron oxides, a double-beam spectrophotometer was used to optically measure the transmission spectra. The spectrophotometer deploys a unique, single monochromatic design to detect wavelength penetration in the range of 240 to 2600 nm. The Sunscreen base without zinc oxide and iron oxides (control) blocked over 80% of ultraviolet-C and ultraviolet-B but did not block ultraviolet-A, visible light, or near-infrared. The novel low viscosity zinc oxide sample blocked almost over 90% ultraviolet, but did not block visible light and near-infrared sufficiently. However, the samples with the novel low viscosity zinc oxide, iron oxides and erioglaucine blocked almost over 90% of ultraviolet, visible light and near-infrared. It can be concluded that this novel combination of low viscosity zinc oxide, iron oxides and erioglaucine is effective at blocking ultraviolet, visible light and near-infrared radiation. The results of this study imply that sunscreens that provide comprehensive photoprotection from ultraviolet through to near-infrared should be adopted to prevent skin photodamage.

Keywords

Anti-Photoageing, Photoimmunosuppression, Photoprotection, Sunscreen, Ultraviolet, Visible Light, Near-Infrared

1. Introduction

Ultraviolet (UV) radiation only accounts for approximately 7% of the sun's total energy output reaching the earth. The remaining 90% is made up of approximately 50% near-infrared (NIR) and 40% visible light (VL). Increasingly, clinical and histologic evidence is revealing that NIR and VL also contribute significantly to photoaging and many other common skin disorders. However, NIR and VL are not effectively blocked by photoprotective materials including sunscreens, protective fibers, umbrellas, eyewear, and window glass film coatings [1]-[15]. Hyperpigmentation, inflammation, erythema, and photodermatoses (including polymorphic light eruption, solar urticaria, and porphyrias) are among the documented skin conditions negatively impacting human skin and deeper tissues [16].

When innate biological photoprotection and repair are inadequate or impaired, chronic photoimmunosuppression, photocarcinogenesis, long-lasting vasodilation, skin sagging, ptosis, hyperpigmentation and other manifestations of skin photodamage/photoaging can be induced by NIR exposure, producing biological effects that impact not just skin, but deeper muscles and also structures of the eye including the retina and lens [1]-[13] [17] [18].

The inability of global sunscreens (SPF50+, PA+++ or PA++++) to protect skin against the entire solar spectrum (UV, VL and NIR) has been reported by the authors in previous studies [10] [12]. The development and deployment of photoprotective materials that are effective against UV, VL and NIR should be adopted as a high priority given the lack of complete solar attenuation provided by current sunscreen technologies and the threat to human skin health posed by these combined wavelengths when skin is exposed daily to biologically active doses of electromagnetic spectral radiation [1]-[15]. Enhanced photoprotection against UV, VL and NIR can be provided by new topical formulations containing metallic oxides and synthetic dyes [15] [19]. Melasma lesions and relapses, for example, were shown to improve in a study involving broad-spectrum sunscreens containing various combinations of zinc oxide, iron oxide and titanium dioxide [20] [21]. Various researchers have focused on the ability of iron oxides, specifically iron oxides red, yellow and black to efficiently block VL and NIR [13] [22]. While inorganic sunscreens, in particular zinc oxide and titanium dioxide effectively absorb UV wavelengths (not reflecting or scattering incident photons), they offer limited protection against VL and NIR [22] [23]. However, it has been established that engineered blends of zinc and iron oxides at various particle sizes are capable of providing broad and effective attenuation of VL [22].

A water-in-oil microemulsion tinted sunscreen containing an array of large particle size zinc and red/yellow/black iron oxides, combined with erioglaucine (a synthetic blue dye with a maximum absorption of 628 nm) was used in this study. A double-beam spectrophotometer was used to investigate the entire solar spectrum blocking potential of this novel low viscosity zinc oxide/iron oxide/erioglaucine tinted sunscreen formulation.

2. Materials and Methods

2.1. Sunscreens Evaluated

Three variations of metal oxides contained in tinted sunscreens and a control sample (sunscreen base without zinc oxide, iron oxides or erioglaucine) were used in this study (Table 1, Figure 1). One is a sample containing novel low viscosity zinc oxide, the second contains yellow/red/black iron oxides and erioglaucine and the third is a sample containing low viscosity zinc oxide yellow/red/black iron oxides and erioglaucine. In order to best distribute the sunscreens over the skin and guarantee their stability within the system and on the skin, a combination of rheology modifiers, polymers, sun filter stabilizers, glycols and esters was created. Additional active ingredients have been incorporated to support cosmetic claims such as soothing and moisturizing.

Table 1. Samples compositions in metal oxides and erioglaucine.

Sample	Sunscreen Actives
1	Sunscreen base without zinc oxide, iron oxides or erioglaucine
2	Sunscreen base with the novel low viscosity zinc oxide
3	Sunscreen base with iron oxide yellow/red/black and erioglaucine without any zinc oxide
4	Sunscreen base with the novel low viscosity zinc oxide, yellow/red/black iron oxides and erioglaucine

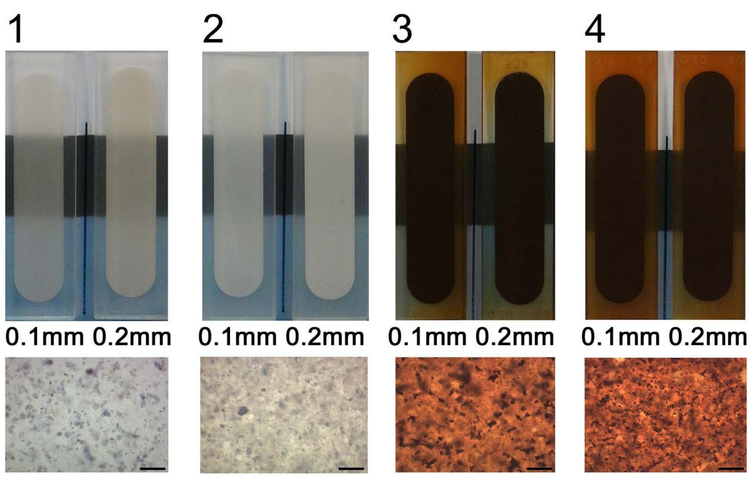

Figure 1. Sunscreen samples in sapphire cuvette with a thickness of 0.1 mm and 0.2 mm. Microscopic photos shown below each sample, scale bars = 1000 μm (magnification: ×40).

2.2. Optical Evaluation of Sunscreens Using Transmission Spectra

Self-recording spectrophotometer U-4000 (Hitachi, Tokyo, Japan) covering wavelengths from 240 to 2600 nm was used to optically measure the transmission spectra for each sample.

Distilled water was applied between the quartz glass cell, and pressed sufficiently to make the thickness of the distilled water so thin that it could be ignored, then calibration was performed and set this state to 100% transmittance. Each sample was embedded in a sapphire cuvette with a thickness of 0.1 mm and 0.2 mm, simulating the practical use one human skin. Each sample was then placed in front of the integrating sphere and irradiated with a spectrophotometer. Transmittance was evaluated by the amount of light that enters the cell into the integrating sphere.

3. Results

Blocking abilities against UV-C (100 - 280 nm), UV-B (280 - 315 nm), UV-A (315 - 400 nm), VL (400 - 760 nm), and NIR of each sunscreen sample are shown in **Table 2**. The results of the transmission spectra of sunscreens are shown in **Figure 2**.

Samples containing zinc oxide and/or iron oxides with a thickness of 0.1 mm and 0.2 mm blocked 89.2% - 97.7% of UV-C, 94.2% - 97.8% of UV-B, 92.5% - 99.9% of UV-A, 58.8% - 99.9% of VL, and 33.8% - 99.6% of NIR (**Table 2**). Sunscreen base without zinc oxide, iron oxides or eriogluacine blocked UV-C and UV-B over 80%, but did not block UV-A, VL, and NIR sufficiently (**Table 2**). The samples with novel low viscosity zinc oxide only blocked almost over 90%

Table 2. Blocking abilities of sunscreen samples.

	Blocking abilities				
	UV-C	UV-B	UV-A	VL	NIR
1. Sunscreen base without zinc oxide, iron oxides or eriogluacine (0.1 mm)	83.8% - 91.7%	91.3% - 91.8%	62.6% - 97.6%	37.2% - 60.4%	19.5% - 46.4%
1. Sunscreen base without zinc oxide, iron oxides or eriogluacine (0.2 mm)	80.9% - 90.3%	89.4% - 90.3%	81.6% - 98.3%	49.5% - 79.5%	28.0% - 66.6%
2. Sunscreen base with zinc oxide only (0.1 mm)	91.1% - 95.7%	95.3% - 95.8%	92.5% - 99.5%	58.8% - 91.2%	33.8% - 58.7%
2. Sunscreen base with zinc oxide only (0.2 mm)	89.2% - 94.8%	94.2% - 94.8%	94.5% - 99.4%	71.3% - 97.8%	48.5% - 76.6%
3. Sunscreen base with iron oxide and erioglaucine (0.1 mm)	93.6% - 96.8%	96.3% - 96.9%	96.4% - 99.7%	91.0% - 99.8%	79.9% - 90.9%
3. Sunscreen base with iron oxide and erioglaucine (0.2 mm)	95.3% - 97.7%	97.3% - 97.8%	97.5% - 99.9%	98.4% - 99.9%	94.5% - 98.4%
4. Sunscreen base with zinc oxide, iron oxides and erioglaucine (0.1 mm)	94.6% - 97.4%	97.3% - 97.6%	97.3% - 99.9%	98.2% - 99.9%	91.9% - 98.1%
4. Sunscreen base with zinc oxide, iron oxides and erioglaucine (0.2 mm)	92.7% - 96.9%	96.5% - 97.0%	96.6% - 99.8%	99.5% - 99.8%	97.5% - 99.6%

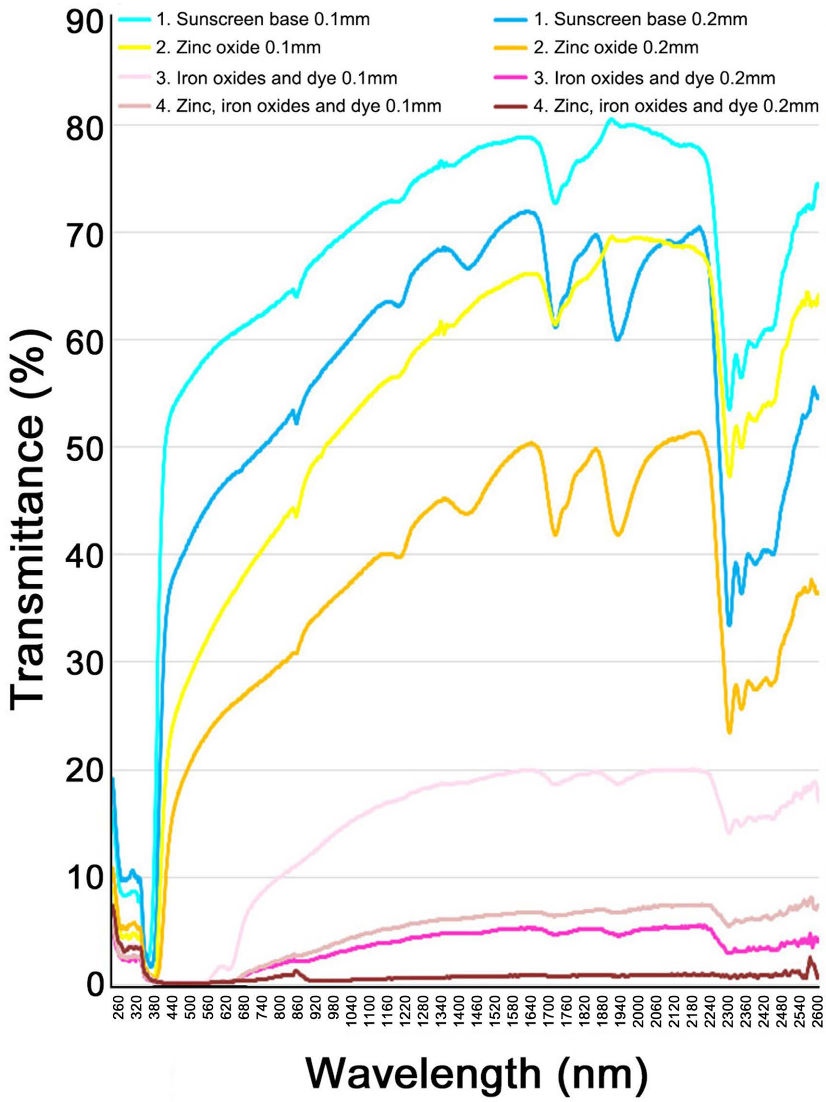

Figure 2. Optical evaluation of sunscreen samples using transmission spectra.

UV, but did not block VL and NIR sufficiently (**Table 2**). The samples with iron oxides and erioglaucine blocked almost over 90% UV, VL, and almost over 80% NIR (**Table 2**). The sample with novel low viscosity zinc oxide, iron oxides and erioglaucine (0.1 mm width) blocked almost over 90% UV through to NIR (**Table 2**). The sample with novel low viscosity zinc oxide, iron oxides and erioglaucine (0.2 mm width) blocked almost over 90% UV, over 99% VL and over 97.5% NIR (**Table 2**).

Transmission spectra demonstrated that the sample with novel low viscosity zinc oxide, iron oxides and erioglaucine effectively blocked from UV through to NIR, and significant difference was observed compared to the samples with novel low viscosity zinc oxide alone and with iron oxides erioglaucine alone, especially in the VL and NIR spectrum, respectively. Significant difference was not observed in the sample containing novel low viscosity zinc oxide, iron oxides and erioglaucine around the UV and VL spectrum between 0.1 mm and 0.2 mm width (**Figure 2**).

4. Discussion

Over 90% of incident solar radiation affecting the Earth surface consists of VL and NIR, and intensive or continuous exposure to VL and NIR, when combined with UV, also contributes to photodamage, photoageing, skin diseases, and skin neoplasms [1]-[13]. VL alone or in combination with NIR generates reactive oxygen species, increases collagen degradation, and leads to DNA damage [14] [24], which results in photoageing. Compounding this problem, the global sunscreen industry has not yet embraced effective formulation technologies designed to filter VL and NIR [12] [13] [15]. As the biological effects of incident solar energy (UV, VL and NIR) are significant and due to the lack of sunscreens offering protection beyond UV, enhanced photoprotection from UV through to NIR is necessary for preventing photoageing [12] [13] [15] [25].

Iron oxide, titanium oxide and various other pigments provide protection against VL-induced pigmentation [26]. For example, yellow iron oxide reduced VL-induced pigmentation [27], red and black iron oxides block from UV through to NIR [13]. Tinted sunscreens can reduce the appearance of cutaneous hyperchromias [25], and tinted mineral sunscreens protect more effectively than nontinted sunscreens, since they block UV and VL [22].

In our prior study, we demonstrated that commercially available sunscreens blocked UV-C and UV-B sufficiently (approximately 99%) [12]. However, most samples evaluated did not block over 99% of UVA, and did not effectively block VL and NIR [12]. This could explain increasing levels of photodamage being reported despite the worldwide prevalence of sunscreen usage [12] [13].

In this study, to investigate the comprehensive photoprotective ability of novel low viscosity zinc oxide, iron oxides and erioglaucine tinted sunscreen formulations, a double-beam spectrophotometer was used to optically measure the transmission spectra. All of samples containing metal oxide blocked almost over 90% of UV, over 60% of VL, and over 30% of NIR.

The samples with novel low viscosity zinc oxide blocked almost over 90% UV, and blocked VL and NIR sufficiently, comparing with the control sample without zinc oxide or iron oxides. The novel low viscosity zinc oxide dramatically enhanced the blocking effect from UV through to NIR. The samples with iron oxides and erioglaucine blocked almost over 90% UV, VL, and almost over 80% NIR. In particular, the iron oxides and erioglaucine enhanced formulations augmented the blocking ability throughout the VL and NIR spectra. The combination sample containing novel low viscosity zinc oxide, iron oxides and erioglaucine (0.1 mm width) blocked almost over 90% UV through to NIR, and similarly 0.2 mm width blocked almost over 90% UV, over 99% VL and over 97.5% NIR. The iron oxide and erioglaucine samples (0.1 mm width) blocked VL (400 - 560 nm) sufficiently (over 96%) comparing with samples without iron oxides nor erioglaucine. In wavelengths longer than 560 nm, the combination samples containing novel low viscosity zinc oxide, iron oxides and erioglaucine (0.1 mm, 0.2 mm width) exhibited enhanced photoprotection, from 92% to 98%, respectively.

These results suggest that both novel low viscosity zinc oxide, iron oxide and erioglaucine sunscreens are highly effective and should be considered for comprehensive photoprotection.

This unique combination of large particle size zinc oxide, combined with iron oxides yellow/red/black and erioglaucine in a low viscosity water-in-oil formulations is transparent on all Fitzpatrick skin types and appeals to consumers due to its ease of application and lightweight skin feel. The sheer viscosity delivery system of this formulation facilitates an even distribution of the metal oxide particles over the skin designed for an optimum protection against UV, VL and NIR radiation.

Fair skin tends to wrinkle and sag earlier in life [28] [29], and characteristic age-related skin changes occur at a more accelerated rate in fair skin people [30]. Dark skin individuals will photoage slower compared to fair skinned individuals. The novel low viscosity zinc oxide used in this study is transparent, which appears to be beneficial in achieving comprehensive and cosmetically elegant photoprotection.

It should be noted that this was a preliminary study based on a relatively small number of metal oxide combinations. Further studies are needed in larger numbers, including various types and concentrations of metals and ingredients for sunscreens and in investigation of biological effects of VL and NIR.

5. Conclusion

This novel low viscosity combination of zinc oxide, iron oxides and erioglaucine sunscreens is effective at blocking UV, VL and NIR radiation. The results of this study reinforce that our biological colour of the skin and subcutaneous tissues is conserved for comprehensive photoprotection, and that while current sunscreens provide adequate UV protection, further development should continue to extend sunscreen photoprotection to include VL and NIR for a holistic skin protection from solar damage.

Disclosure

The authors disclose that this study was entirely funded by RATIONALE Skincare Pty Ltd, Victoria, Australia.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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